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Pinyon-Juniper Volume Equations for Arizona Hualapai and Havasupai Indian Reservations[1]

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ABSTRACT

Volume prediction equations were developed for pinyon and juniper trees on the Hualapai and Havasupai Indian Reservations in Arizona. Application of the equations requires measurements of total height and tree diameter near the root collar. Results are presented in equation and tabular formats. Volume equation construction and equation reliability are discussed.

KEYWORDS: *Pinus edulis, Juniperus osteosperma,* volume table

INTRODUCTION

The Hualapai and Havasupai Indians are interested in management of their northern Arizona pinyon-juniper (P-J) lands for firewood production. The tribes depend upon P-J for personal uses and for revenue from commercial sales. To meet the need for current P-J management information, an inventory of the Hualapai and Havasupai Indian Reservations was conducted in 1984 and 1985 (USDA 1984). Determination of total P-J volume was an important objective of the inventory. Because direct volume measurement is time consuming and costly, data were collected in the inventory on a subsample of trees for later volume equation development. This paper reports the equation construction from these data.

FIELD MEASUREMENTS

Field crews selected one to six trees for volume estimation on each of the 135 plots (fig. 1). The fixed-area plots encompassed a fifth acre when crown cover of the surrounding stand was less than 30 percent, and encompassed a tenth acre when crown cover was more than 30 percent. Within each plot one pinyon and one juniper were randomly selected from each of three diameter classes, 3.0 to 9.9, 10 to 18, and >18 inches diameter at root collar (DRC). Volume estimation was done using visual segmentation, a method of counting the numbers of wood segments within a tree (Born and Chojnacky 1985). Wood segments were determined by dividing tree stems and branches into 1-foot to 6-foot length sections using 2-inch diameter classes. Cubic foot volume was computed for each segment using Huber's log formula (Husch and others 1982, p. 101). For each tree, segments that included wood and bark of all live and dead stems and branches larger than 1.5 inches in diameter were summed into a gross cubic foot volume.

Other tree variables measured for volume equation development were total height, DRC, and number of basal stems. For trees forking at the root collar, an equivalent diameter (EDRC) was calculated for use in place of DRC:

$$\mathrm{EDRC} = \sqrt{\sum_{i=1}^{n} D_i^2} \qquad (1)$$

where

D_i = basal diameter of each stem

n = number of basal stems 1.5 inches or larger.

Species sampled were *Juniperus monosperma* (Engelm.) Sarg., *J. osteosperma* (Torr.) Little, *Pinus edulis* Engelm., and *P. edulis* var. *fallax* Little. In the analysis, the data were grouped by genus because only five of 299 juniper were *J. monosperma* and only 21 of 181 pinyon were *P. edulis* var. *fallax*. Table 1 includes a summary of the raw data.

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[1] This study was a cooperative effort between the Bureau of Indian Affairs, Intermountain Research Station, and the Hualapai Tribal Council Forestry Department who collected the field data.

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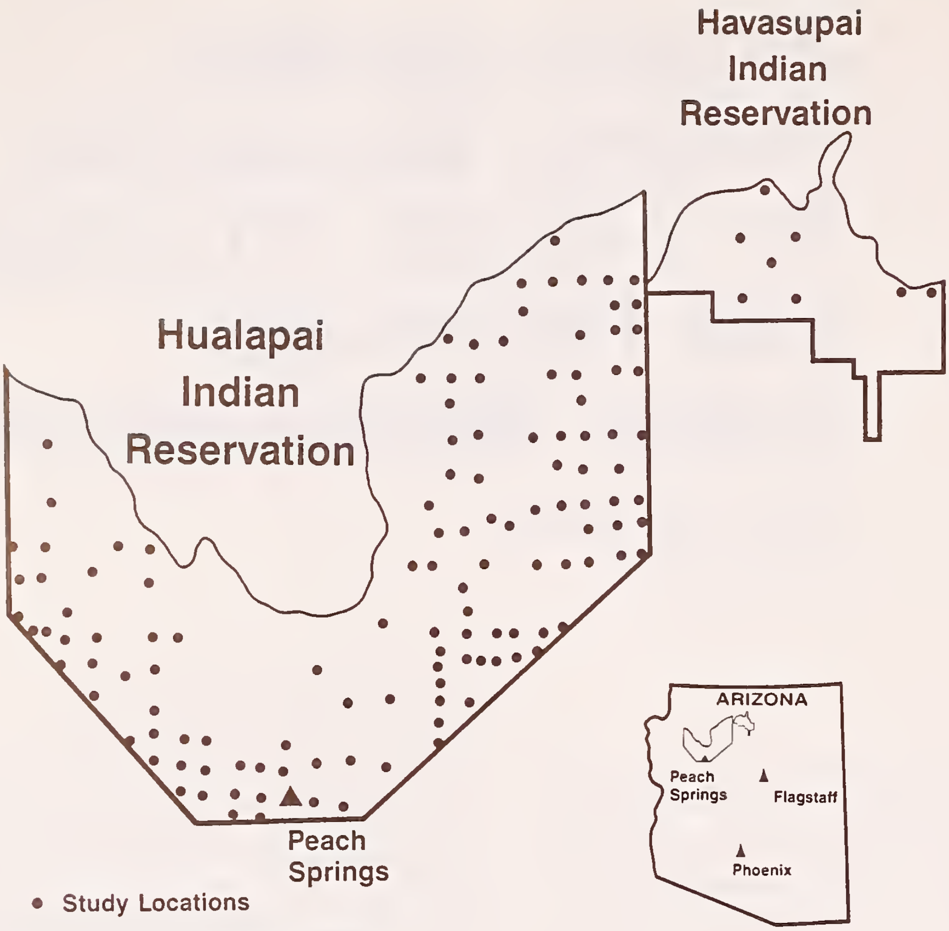

Figure 1—Map of 135 study locations.

Table 1—Summary of Hualapai and Havasupai P-J volume data

Genus	Basal stems	Number of trees	Mean volume	Mean DRC/EDRC	Mean height
			Ft^3	*Inches*	*Feet*
Juniper	Multiple	84	10.9	15.1	14.5
	Single	215	8.4	11.3	14.0
	Multiple/single combined	299	9.1	12.4	14.1
Pinyon	Multiple	6	9.1	12.6	16.0
	Single	175	6.0	9.0	17.2
	Multiple/single combined	181	6.1	9.2	17.2

MODELING

A single volume prediction model was sought to estimate volume of all tree sizes represented in the data. Past research has shown DRC, total height, and numbers of basal stems (STEMS) to be important P-J volume prediction variables (Howell 1940; Reveal 1944; Clendenen 1979; Chojnacky 1985).

A simple linear model using a combination variable, DRC squared times height (DRSQH), proved best among initial choices:

$$V = \beta_0 + \beta_1 X \qquad (2)$$

where

V = gross cubic foot volume of wood and bark from all stems and branches larger than 1.5 inches in diameter

X = DRSQH divided by 1,000

β_i = parameters estimated from data.

The STEMS variable was not used because it added little to the model. Perhaps this was because the data included too few multiple-stem trees (see table 1) or because EDRC is a good enough approximation to DRC that no additional variable is needed to distinguish multiple-stem from single-stem trees.

To achieve good volume prediction throughout the range of tree sizes, the simple linear model (eq. 2) was modified to a two-part model:

$$V = \begin{cases} \beta_0 + \beta_1 X + \beta_2 X^2 & \text{for } X \leqslant X_0 \\ \beta_3 + \beta_1 X + \beta_4 / X & \text{for } X > X_0 \end{cases} \qquad (3)$$

where

V, X, β_i = same as for eq. 2

X_0 = 5

The two-part volume model was conditioned to be both smooth and continuous at the point where the two equations meet. This was done by imposing two restrictions on the model:

$$\beta_3 = \beta_0 + 3\beta_2 X_0^2 \tag{4}$$

$$\beta_4 = -2\beta_2 X_0^3 \tag{5}$$

The restrictions were obtained by equating the two parts of equation 3 for $X = X_0$ and by equating the first derivation of the two parts of equation 3 at the point $X = X_0$.

The "joining point" ($X_0 = 5$) was chosen to roughly separate the large trees from the rest. For juniper, the joining point corresponded to trees with DRC of about 18 inches. For pinyon, it corresponded to a tree DRC of about 15 inches. Parameters for the two-part model (eq. 3) were determined using weighted regression with DRSQH to the -1.5 power as the weight (Schreuder and Anderson 1984). Final parameter estimates and tabulated volume predictions are given in tables 2 and 3.

RELIABILITY DISCUSSION

Results of regression goodness-of-fit analyses are summarized in table 4. The coefficient of determination (R^2) and coefficient of variation (*CV*) were computed without the influence of regression weights to avoid possible misinterpretation. Had weights been used, these regression statistics would have appeared much better because in this case the weights minimized the impact of the larger, highly variable trees. On the other hand the confidence intervals (*CI*) were computed using the regression weights (SAS 1985) because no unweighted alternative seemed reasonable.

The R^2 indicated sufficient fit of the volume model to the data for trees less than 15 to 18 inches DRC, but it indicated a poor fit for larger trees. The coefficient of variation (*CV*) showed large variation for the regression standard error to mean volume ratio. The consequence of this large variation on future predictions was assessed by constructing 95 percent confidence intervals (*CI*) to predict sample means.

Results for four sample sizes used to predict the median size tree in two DRC classes are illustrated in table 4. For example, if 10 juniper trees about 10 inches in DRC were measured for volume prediction, the expected true volume would lie in an interval plus or minus 28 percent of 3.1 ft^3 (2.2 to 4.0 ft^3). If 30 junipers of 10 inches were sampled, the expected true volume would lie in a smaller interval of plus or minus 17 percent of 3.1 ft^3 (2.6 to 3.6 ft^3). A sample size of 50 would further reduce the confidence intervals, but the amount of confidence interval reduction in relation to sample size diminishes considerably beyond sample size 30.

Table 2—Juniper gross outside bark volume[1] of stem and branch wood larger than 1.5 inches in diameter

DRC	Height (feet)																Number of trees
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	
Inches	*Cubic feet*																
4	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.7								41
6	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5	2.7			31
8	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.9	3.2	3.6	3.9	4.2	4.6	4.9	5.3	5.6	29
10	1.0	1.5	2.0	2.5	3.0	3.5	4.1	4.6	5.1	5.7	6.2	6.8	7.3	7.9	8.5	9.0	38
12		2.1	2.9	3.6	4.4	5.2	6.0	6.8	7.6	8.4	9.2	10.0	10.9	11.7	12.6	13.5	39
14		2.9	4.0	5.0	6.1	7.2	8.3	9.4	10.5	11.7	12.9	14.1	15.2	16.4	17.5	18.6	30
16			5.3	6.7	8.1	9.6	11.1	12.6	14.1	15.7	17.2	18.6	20.0	21.4	22.8	24.2	17
18			6.8	8.6	10.5	12.4	14.3	16.3	18.1	19.9	21.7	23.4	25.2	26.9	28.6	30.3	13
20			8.5	10.8	13.2	15.6	17.9	20.1	22.3	24.4	26.6	28.7	30.7	32.8	34.9	36.9	24
22				13.3	16.2	18.9	21.6	24.2	26.8	29.3	31.8	34.3	36.8	39.3	41.7	44.2	15
24				16.0	19.3	22.5	25.5	28.6	31.6	34.5	37.5	40.4	43.4	46.3	49.2	52.1	10
26					22.6	26.2	29.7	33.2	36.7	40.2	43.6	47.0	50.4	53.8	57.2	60.6	8
28					26.1	30.2	34.2	38.2	42.2	46.2	50.1	54.1	58.0	62.0	65.9	69.8	1
30					29.7	34.4	39.0	43.5	48.1	52.6	57.1	61.7	66.2	70.7	75.2	79.7	3
32						38.8	44.0	49.2	54.3	59.5	64.6	69.7	74.8	80.0	85.1	90.2	0
34						43.5	49.3	55.2	61.0	66.7	72.5	78.3	84.1	89.8	95.6	101.4	0
Number of trees	3	12	30	28	45	45	42	38	23	15	10	4	2	2	0	0	299

[1] Volume $= -0.05 + 2.48 \cdot X + 0.057 \cdot X^2$ for $X \leqslant 5$
$4.24 + 2.48 \cdot X - 14.29/X$ for $X > 5$
where: $X = \mathrm{DRC} \cdot \mathrm{DRC} \cdot \mathrm{Height}/1{,}000$.

Table 3—Pinyon gross outside bark volume[1] of stem and branch wood larger than 1.5 inches in diameter

DRC	Height (feet)																		Number of trees
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	
Inches	*Cubic feet*																		
4	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.7										34
6	0.3	0.5	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8					32
8	0.6	0.9	1.2	1.6	1.9	2.3	2.6	3.0	3.3	3.7	4.0	4.4	4.7	5.1	5.5	5.9	6.2	6.6	27
10	0.9	1.5	2.0	2.5	3.1	3.6	4.2	4.8	5.3	5.9	6.5	7.1	7.7	8.3	9.0	9.6	10.2	10.9	32
12		2.2	3.0	3.7	4.6	5.4	6.2	7.1	8.0	8.9	9.8	10.7	11.6	12.6	13.6	14.6	15.6	16.5	24
14		3.0	4.1	5.2	6.4	7.6	8.8	10.0	11.3	12.6	13.9	15.3	16.6	17.9	19.1	20.3	21.5	22.7	16
16			5.5	7.0	8.6	10.2	11.9	13.6	15.4	17.1	18.7	20.3	21.9	23.4	24.9	26.3	27.8	29.2	5
18			7.1	9.1	11.2	13.3	15.6	17.7	19.8	21.7	23.7	25.5	27.4	29.2	30.9	32.7	34.5	36.2	5
20			9.0	11.5	14.2	17.0	19.5	22.0	24.3	26.6	28.8	31.0	33.2	35.4	37.5	39.6	41.7	43.8	4
22				14.4	17.6	20.7	23.6	26.3	29.1	31.7	34.3	36.9	39.5	42.0	44.6	47.1	49.6	52.1	1
24				17.5	21.1	24.5	27.8	30.9	34.1	37.2	40.2	43.2	46.3	49.2	52.2	55.2	58.2	61.1	1
26					24.6	28.5	32.2	35.8	39.4	43.0	46.5	50.0	53.5	57.0	60.5	63.9	67.4	70.8	0
28					28.3	32.6	36.8	41.0	45.1	49.2	53.2	57.3	61.3	65.3	69.3	73.3	77.3	81.2	0
Number of trees	0	6	9	20	23	11	21	13	24	19	12	4	7	6	1	2	1	2	181

[1] Volume = $-0.07 + 2.51 \cdot X + 0.098 \cdot X^2$ for $X \leqslant 5$
$7.29 + 2.51 \cdot X - 24.53/X$ for $X > 5$
where: $X = \mathrm{DRC} \cdot \mathrm{DRC} \cdot \mathrm{Height}/1{,}000$.

Table 4—Regression statistics from Hualapai and Havasupai P-J volume modeling

Genus	DRC class	Number of trees	R^2	*CV*	Median statistics[1]					
					Predicted volume	Median DRC	95% mean[2] *CI*			
							n = 10	n = 30	n = 50	n = 100
	Inches			*Pct.*	*Ft³*	*Inches*	*Percent*			
Juniper	<18	230	0.77	51	3.1	10	28	17	14	11
	>18	69	.59	35	22.7	21	16	11	9	8
Pinyon	<15	165	.84	42	3.2	9	23	15	12	10
	>15	16	.42	27	26.8	18	14	10	9	9

[1] Statistics based on the median of the DRC class.

[2] Confidence intervals (*CI*) for mean predicted volume for several sample sizes for the median level of DRSQH (roughly median DRC) in each DRC class. *CI*'s are expressed as a percentage of predicted volume for each DRC class.

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